Current Situation and Future Innovations in Arctic Communications

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***Abstract*—This article surveys the unsatisfying communication capabilities in the harsh Arctic regions. By melting of the ice caps, the undergoing change of the north polar area opens new opportunities and, therefore, increases the need for human and machine-to-machine communications. The emerging demands and challenges are reviewed. New satellite systems, architectures, and technologies being deemed as key enablers are highlighted. As also addressed in this article, satellite links could additionally backhaul terrestrial networks for local communications.**

Keywords—Arctic; satellite; maritime; aeronautical; M2M

I. INTRODUCTION

Most commonly, scientists define the Arctic as the region above the Arctic circle, an imaginary line that circles the globe at 66° 32" N. The Arctic is currently experiencing a warmer climate, which is slowly reducing the permanent floating ice cover and making the area more accessible to shipping and other activities. Currently, fishing fleets, cruise ships, and cargo ships are operating already above 80°N, and oil/gas explorations are extending above 75°N. Therefore, the number of stakeholders in these areas will further increase.

Communication infrastructure and associated equipment face a very harsh environment in the Arctic. Because of this rough environment, communication is an essential part for safety of life. However, availability of communication is very limited. The vast geographic areas of the sea and ice do not allow a dense terrestrial communication infrastructure. Geostationary (GEO) satellites can theoretically provide coverage up to 81°N, but the practical limit is typically assumed to be around 76°N. However, polar-orbiting satellites could serve the whole Arctic by using a low earth orbit (LEO) or high elliptical orbit (HEO), e.g., the “Molniya” orbit.

In this article, the current situation and the existing communication possibilities for the Arctic are reviewed. A detailed outline of the communication challenges in Norwegian waters and territories can be found in [1]. A glance at potential high frequency (HF) terrestrial communication in the polar region is also given in [2].

The initial part of this article is addressing the change of this unique region regarding climate and its resulting potentials. The existing and future user needs in communications will be reflected. The main focus of this survey is the requirements for any kind of communication as well as the details on satellite communications. Finally, new architectures and technologies for satellite communications in the Arctic are discussed.

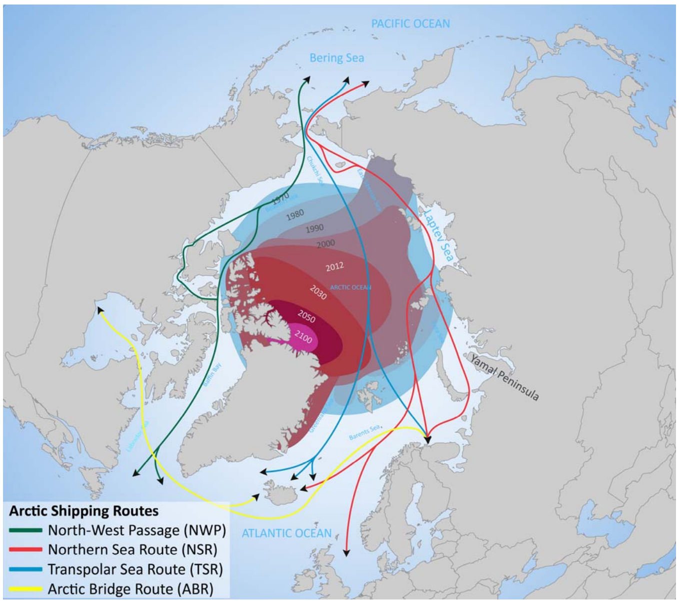


Fig. 1. Arctic shipping routes and expected ice extent until 2100.

II. CHANGES OF THE ARCTIC ENVIRONMENT

During the last decades, the Arctic Ocean has experienced a drastic change in the extension of its floating ice coverage. As shown in Fig. 1, the size of the ice cap has decreased significantly; this trend is being predicted to continue by several scientists. Increased shipping activities are experienced during the last years in the Arctic Ocean, where new routes are also feasible. Mainly, the Northern Sea Route (NSR) along the Russian Arctic Coast is of high interest and already in use by 40-50 transits per year. Scheduled to start in 2017, the north-east of the Yamal Peninsula, Russia at Sabetta, a new liquefied natural gas plant (Yamal LNG) will operate, including 16 new built ice-class tankers. Nevertheless, the melting of the ice cap does not mean a permanent ice-free Arctic Ocean. Even according to the most extreme prognosis for 2050, the North Pole will only be so-called "ice-free", that is, less than 10% of

the water surface is ice covered, during a few months per year. Ships will still be slowed down by icebergs and drifting ice. The current average speed in the NSR is 7–13 knots [3] compared with 21–25 knots in open waters. Furthermore, sailing in these waters require a different class of ships compared with open waters. Moreover, all routes have political difficulties as the respective countries claim parts of them as territorial waters and not as international straits. Anyhow, the reduced ice cap has already allowed shipping in the NSR during the last years by support of ice breakers, not only in case of emergency caused by lack of communication capabilities but also because of areas with still permanent ice coverage (e.g., in the Laptev Sea).

TABLE I. DISTANCES IN KM BETWEEN HARBORS [4], GREEN ARE SHORTEST ROUTES.

Route	Panama Canal	North-West Passage NWP	Northern Sea Route NSR	Suez and Malacca	Savings compared with Panama or Suez routes
Rotterdam – Shanghai	25,588	17,570	15,793	19,550	≤19%
Rotterdam – Singapore	28,994	19,900	19,641	15,750	-
Rotterdam – Vancouver	16,350	14,330	13,445	28,400	≤17%
Rotterdam – Los Angeles	14,490	15,790	15,252	29,750	-
New York – Shanghai	20,880	17,030	19,893	22,930	≤18%
New York - Singapore	23,580	20,310	23,121	18,770	-

However, the overall benefit of the possible shipping routes is questionable: the North-West Passage, the Transpolar Sea Route, and the NSR, see also Fig. 1. There are no large distance savings using these routes between major international ports compared with voyages via the Panama Canal or Suez and Malacca. Only the NSR could save approximately 20% shipping distance between the largest European harbors (Rotterdam, The Netherlands, and Hamburg, Germany) and the largest harbors in China (e.g., Shanghai, Ningbo-Zhoushan, Hong Kong), see Table I. The route between New York and Singapore is even shorter via Suez, and this also applies to routes between Asia and North America, except a few routes from the East Coast to China. Another shorter route via the NSR is between Europe and the North American West Coast [4]. Currently, shipowners are even ordering reduced speed of ships to save fuel costs instead of speeding up the transport. On Arctic routes, there are higher safety requirements: the need for new ship classes, higher risks, and many other uncertainties that are not in favor of shipowners gaining on shorter distances and transport time. Also, the global impact on the environment by shipping through the polar regions is not to be neglected [5].

On the other hand, the warmer climate in the Arctic offers new access to raw materials, gas, and oil, mainly in the Russian, Norwegian, and Canadian regions. Consequently, the largest increase of human activity and communication needs will be toward this local destination traffic instead of transit. Many new ice-strengthened bulk ships are expected to navigate through these waters, for example, Yamal LNG. Also, sea tourism by cruise liners will enter the Arctic region. Finally, these new opportunities in combination with the harsh Arctic environment evolve risks for coastguards toward the responsibility of performing patrol, surveillance, and emergency response tasks. Again, new communication solutions are needed.

III. NEEDS OF CURRENT AND POTENTIAL USERS

Current fishing activities are even more up north than decades before. The same evolves in new areas of eco-tourism and leisure sailing. Additionally, the areas for drilling are explored in the High North, and research activities are permanently running. Finally, cargo shipping as transit or local traffic exists. Since the usage of satellites for collecting ship data via the automatic identification system (AIS), these new developments could be monitored [6].

Independent of the climate change and its consequences, the polar region experiences continuous air traffic since the mid of last century. The number of flights simultaneously present in the Arctic airspace (latitudes above 70°N) during peak period conditions are predicted to steadily increase from 55 at present to more than 160 in 2030 [7]. Not only airliners and cargo flights are taken into account but also general aviation, helicopter flights, nonscheduled flights (e.g., search and rescue (SAR), ambulance, etc.), and military flights.

Many different groups have diverse communication requirements. Offshore oil and gas exploitations, including safeguarding of operations, installations, transportation, and associated ports are looking toward high data rates until the platforms are operational and linked via fiber cables to the main land. Also, crew welfare is a rising issue toward an attractive employment, not only on ships but also on explorations and for people living in these remote areas. Permanent monitoring of fish farms, aquaculture installations, and their associate activities request continuous flow of information, for example, machine-to-machine (M2M) communications for "health" monitoring of the systems. Within the maritime area, traffic and environmental safety monitoring is needed, including the distribution of navigational data, for example, navigational warnings, maritime safety information, and position reporting. Another source of information would be weather and ice information to be distributed over a vast geographic area toward the mariners, fishers, and others. Moreover, authorities (coast guards and homeland security) need reliable and robust communication solutions for defense operations, territorial control, law enforcement of illegal activities, and environmental crime. Also, a robust communication infrastructure is required for aircraft in the polar region [7]. Finally, research activities such as ice studies and meteorological and hydrological research require communication systems for monitoring and controlling. In Table II, the demands on data throughput for different applications in the maritime [8] and aeronautical domain are illustrated.

IV. Existing and Planned Communications Systems

Broadband communication is currently unavailable in the Arctic. The GEO Inmarsat satellite and very small aperture terminal (VSAT) satellites provide a theoretical coverage up to 81°N. Although the practical limit is assumed to be around 76°N. Attempts to optimize signal reception of the Ka-Sat by Eutelsat at the shelf of the Arctic Ocean in North-Western regions of Russia prove the practical difficulties of GEO satellites for polar areas [9]. Because of an inclination of 52° of the LEO orbits by the Globalstar satellite system, the Arctic is not fully covered. Also, the second generation of Globalstar satellites is using the same orbits. The only notable LEO satellite communications system constellation covering the Arctic is Iridium, comprising 66 satellites in six polar LEO planes at altitudes of approximately 780 km, providing a maximum voice and data service of 130 kbit/s. Nevertheless, because of the multi-hop architecture for reaching one of the four Earth stations via feeder links, high latencies exist in the system up to 500 ms for voice and 20 s for data [10]. Furthermore, the non-commercial US tactical satellite communications system MUOS (Mobile User Objective System) covers in a geosynchronous earth orbit the Arctic by up to 384 kbit/s.

Based on a Russian Federal Space Agency program of the early 1990s, the Gonets system has been commercially operational since 2000, using a LEO orbit altitude of 1400 km with an inclination of 82.5°. In total, 5 satellites are in orbit today. The two Gonets-D-1 support a data rate of 2.7 kbit/s, and the three Gonets-D1M satellites, up to 64 kbit/s.

A distress alert detection satellite system for SAR is provided by the Cospas-Sarsat program. Six LEO satellites are operational for collecting distress signals at 406 MHz in an orbit at an altitude of approximately 850 km and with emphasis on the polar regions. Since May 2011, SAR responsibilities in the Arctic are governed by the Arctic Search and Rescue Agreement [11].

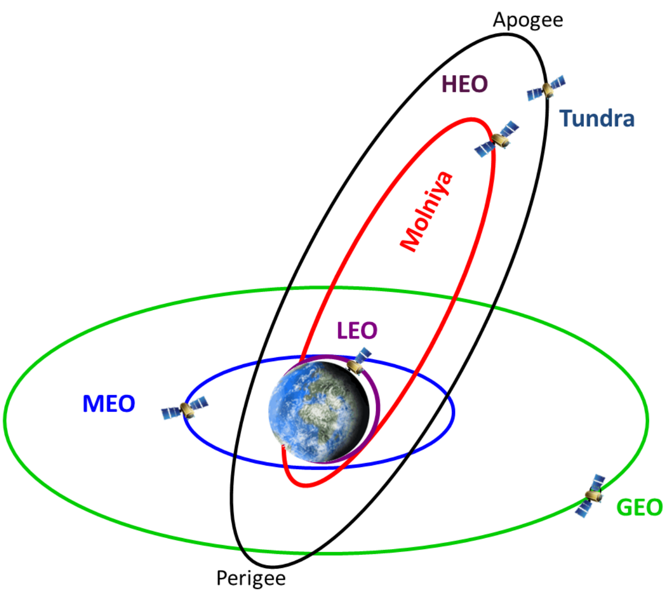
Terrestrial systems also exist in the Arctic, although very limited in coverage. The current voice communications for maritime applications (ship-to-ship or ship-to-shore) is based on analog technologies in the very high frequency (VHF) band, mainly Channel 16 at 156.8 MHz but also Channels 6 and 13 with a range of up to 60 nautical miles (NM). Other communication systems are operating in the medium-frequency (MF) and high-frequency (HF) band with analog and a few evolving narrowband digital services, such as digital selective calling (DSC), Navigational Telex (Navtex), Maritime Safety Information (MSI), Narrowband Direct Printing (NBDP), and other HF digital data services. However, the dependence on signal reflection from the ionosphere is rendering MF/HF communications unreliable, although the coverage distances may be very large during favorable ionospheric conditions. A future MF/HF digital data service for MSI would include Navigational Data (NAVDAT). The NAVDAT operates in the 500-kHz band (MF) for digital broadcasting of maritime safety and security-related information from shore to ship with 10-kHz bandwidth using OFDM modulation, providing a data rate of about 15 to 25 kbit/s. The coverage is approximately 250/350 NM from the coast station [12]. An overview of the coverage limitations of communication systems in the Arctic are given in Table III.

Maritime communications will experience major changes during the next two decades. The present maritime communication systems, not only for the Arctic, cannot serve the upcoming needs [13]. Several initiatives are currently ongoing within the different organizations, such as the "e-Navigation Strategy" of the International Maritime Organization (IMO) and the IALA Maritime Radio Communication Plan [12], with the ultimate overall goal of modernizing statutory maritime communication systems with an increased reliance on robust communications, including satellite communications. This will also impact the communications in the Arctic.

In addition, only HF communications exists over the whole Arctic for aeronautical communications. Approximately at least once an hour, the pilots report their position, altitude, and speed. Limited emergency landing sites, cold fuel conditions, and the clustering of the air traffic control regions increase the need of robust and reliable communications.

A. *Potential Satellite Orbits*

Satellite orbits currently utilized for satellite communication (SatCom) and satellite navigation (SatNav) are portrayed in Fig. 2, along with their major orbital characteristics [1].



Orbit		Altitude [km]	
		Perigee	Apogee
LEO: low earth orbit		200–2 000; normally: 600–1 000	
MEO: medium earth orbit		2 000–GEO; normally: 10 000–20 000	
GEO: geostationary orbit		35.786	
HEO: high elliptical orbit	Molniya (12 h)	~500	~40 000
	Tundra (24 h)	~24 000	~48 000

Fig. 2. Satellite orbits and major orbital characteristics.

SatCom systems utilizing polar LEO orbits serve the polar regions on a regular basis (e.g., approximately every 100 min). However, communication between a LEO and a ground station is yet to be granted for the Arctic. Therefore, multiple inter-

satellite hops are needed to communicate with a ground station [10]. In contrast to GEO and LEO satellite orbits, there are polar-oriented orbits capable of supporting broadband communications, notably HEOs. For spotlighting the Arctic, the apogee needs to be in the zenith for the pertinent area. During approach and descend from the apogee, there is a long period of visibility (up to 16 hours) until the satellite turn toward the perigee. Two HEO orbits have been in use by the Russians since the mid-1960s and are still in use today: The Molniya orbit (~500 km perigee, ~40,000 km apogee altitude, 12 hours of orbital period, and about 10 hours of Arctic sight) and the Tundra orbit (~24,000 km perigee, ~48,000 km apogee altitude, 24 hours of orbital period, and about 16 hours of Arctic sight). Furthermore, HEOs provide a quasi-stationary perspective. Apogee height is approximately the GEO height, and thus, GEO technologies can be reused (slightly modified), resulting in cost savings and risk reduction.

B. Upcoming and Planned Polar Satellite Systems

Within 2015, the second generation of Iridium satellites, Iridium NEXT, are planned to be launched. Data rates of up to 1.5 Mbit/s in L-band will be provided by 70 LEO satellites in total (66 in simultaneous operation) covering the whole globe. In 2017, the Iridium NEXT system should allegedly be fully operational, also in the Arctic.

The Canadian Space Agency (CSA) had planned launching two satellites operating in HEO orbits with apogee of 39,500 km and perigee of 600 km in 2016. This could have provided a 24/7 broadband communication services and enabled monitoring of the arctic weather. However, having unsuccessful straining to realize this Polar Communication and Weather mission (PCW) since 2008, the Canadians have obviously decided to reorganize the project. The Canadian Government is now reaching out to other countries and companies for partnership on a massive satellite program to provide “high-capacity, continuous communication services” and improved meteorological data in the Arctic [14]. At the same time, Canada's Department of National Defence plans its own satellite program for northern surveillance with the “Radarsat Constellation Mission” [15], planning a three-satellite launch in 2018 to help with maritime surveillance (ice, wind, oil pollution, and ship monitoring), disaster management, and ecosystem monitoring. The system offers up to four passages per day in Canada's far north and several passages per day over the Northwest Passage.

The CSA planned the launching of the Maritime Monitoring and Messaging Micro-Satellite (M3MSat) already in 2014. The M3MSat will have a sun-synchronous polar orbit with the main goal of collecting automatic identification system (AIS) signals for maritime surveillance in the Canadian Arctic waters. Additionally, it carries a low data rate system for two-way communication with measurement buoys or other surveying stations.

Providing a variety of remote-sensing tasks, for example, monitoring of environmental conditions, and also enabling reliable communications and navigation in an economically crucial region for Russia, the Russian Federal Space Agency is planning the Arktika network. The initial concept of the Arktika project was presented already in 2007, primarily as an earth observation system consisting of four satellites in Molniya orbits, with the main focus on meteorological applications. Since then, the system seems to have gone through several transformations. Most notably, a communication component has been added, where two communication satellites are intended to support broadcasting services, backhaul communications, and mobile satellite services [16]. Currently, this network is allegedly planned for satellites capable of meteorology and emergency communications (Arktika-M), mobile communications (Arktika-MS1), air traffic, navigation signal relay (Arktika-MS2), and radar remote sensing (Arktika-R). This highly ambitious project comprises 10 satellites in total—8 in HEO and 2 in a sun-synchronous polar orbit. Launching of the first satellites have been planned for 2015, whereas launching of those expected to support communications seems to have been postponed until the final part of the mission; it is unknown how committed the Russian space sector is to the project, and the ability of the Arktika system to meet the user requirements in terms of services and capacity is uncertain.

Since 1978, the ARGOS instruments (location and data collection equipment) have been operational on several satellites (currently seven) in polar orbits at an altitude of 850 km. The initiator French Space Agency, Centre National d’Etudes Spatiales (CNES) decided to prepare the launch of the fourth-generation (ARGOS-4) instruments including some communication capabilities scheduled to fly in 2016.

Because 80% of the Arctic traffic is in Norwegian waters [6], the Norwegian Space Center and Telenor are running the ASK (“Arktisk Satellitt Kommunikasjon”) Project, first, evaluating the requirements and needs for two HEO satellites providing continuous broadband in their waters. Phase 1 of the ASK projects was completed late 2013, and Phase 2 has recently been initiated [17]. Telenor has declared that, under current plans, it is contemplating to launch the satellites within six years, that is, around 2020.

Table 4 summarizes the existing and planned satellite systems intended to serve the Arctic with communication capabilities. HEO coverage of the Arctic is hardly foreseen to be realized before 2020 – 2025, if ever being accomplished for this purpose.

V. ARCTIC COMMUNICATIONS SYSTEMS' CHALLENGES

A. GNSS augmentation systems (SBAS/GBAS)

Precise satellite navigation positioning relies on correction signals obtained from fixed stations at known positions (so-called differential satellite navigation). Augmentation of global navigation satellite system (GNSS) is a method of improving the system’s attributes, such as accuracy, reliability, and availability, through the integration of external information from such reference stations into the receiver’s calculation process. Because of the vast open sea areas in the Arctic, adequate ground-based augmentation systems (GBAS) are hardly realizable. Satellite-based augmentation systems (SBAS) utilizing GEO satellites suffer from their coverage shortcoming in the Arctic, for example, the devised European

Geostationary Navigation Overlay Service (EGNOS) system for future Galileo applications. Consequently, novel SBAS/GBAS solutions need careful attention to accommodate user requirements on accurate and reliable GNSS positioning in the High North [1].

B. Weather and Icing

The harsh, unpredictable, and rapidly changing weather conditions in the Arctic frequently cause icing on outdoor equipment, both so-called atmospheric icing due to precipitation and icing created by sea spray (salty ice). Antennas enable any radio system contact with the outside world and, thus, represent the most crucial elements regarding system performance. Icing is one of the most serious problems for numerous antenna installations. Ice buildup not only increases antenna wind load and weight but also often deteriorates the antenna's performance to a point where it is no longer usable for any radio system.

It is often experienced in maritime environments by ice first forming on an antenna that it is usually wet and conductive, particularly if it is the result of saltwater spray. This is the most destructive condition for electrically detuning and deterioration of antenna performance. Subsequently, ice buildup increases and will eventually freeze solid, causing the antenna wind load to escalate to a level where it may be stressed to its breaking point.

Both the ice buildup and (subsequent) melting occur most frequently in an asymmetrical fashion, so one side of the antenna may be more affected than the other. Antennas can also be damaged by flying ice from nearby structures often found on ships and offshore installations. This can often cause catastrophic failures because heavy and large ice sheets often break loose with wind or melting. Consequently, novel robust antenna designs are required for reliable operations of radio systems under adverse weather conditions in the Arctic [1].

C. Vessel Movements

Stabilized antennas must lock into the intended satellite for proper operation, but several conditions, including the vessel's unpredictable gyrations, can instigate a stabilized antenna to drift away from the intended satellite and cause signal blackout and/or harmful interference to adjacent satellites. Because of rather severe roll, pitch, and yaw movements of a vessel during adverse weather conditions, larger nominal elevation angles than 5° are required, and thus, practical problems with less advanced satellite communication terminals may be expected to arise.

VI. New Architectures and Technologies for Arctic

As outlined above, the state-of-the art in Arctic communications demand obviously new architectures and technologies to fulfill user requirements. This section addresses several topics that need be emphasized in paving the road toward novel innovative solutions and further associated research. The major goal should be to close today's existing communication gap until adequate broadband coverage is obtained by utilizing new satellite systems and other space-based assets in combination with advanced terrestrial systems.

A. Hybrid Architecture

The lack of land infrastructure in the Arctic is a limiting factor for fast emerging new communication systems. Therefore, a multitier approach using satellites, unmanned aerial systems (UASs), and extended coverage by terrestrial infrastructure could become a solution for the Arctic environment. Fig. 3 shows a possible architecture of such an approach. The high altitude platforms (HAPs) and/or UAVs could serve as relay stations between the satellite platform (GEO, LEO, MEO or HEO, whichever being the most appropriate) and the user terminals or terrestrial base stations embraced by the 'grey cone' [1]. Further, this infrastructure could vary between a standalone HAP system and an integrated terrestrial HAP satellite system. To achieve a large coverage area of about 400–500 km footprint diameter, and simultaneously remain in relatively calm tropospheric wind conditions, the HAPs/UASs should preferably fly at a height of about 20 km. Larger areas could be covered by several cross-linked HAPs/UAVs. Hence, they could also be visible from a GEO satellite due south up to approximately 85.8°N, which could provide a reliable data link with a GEO satellite up to approximately 83°N. From 83°N latitude, the longitudinal distance to the North Pole is only about 800 km, which is the same distance from 83°N down to 76°N, where communication between vessels and GEO satellites is normally of acceptable quality-of-service (QoS).

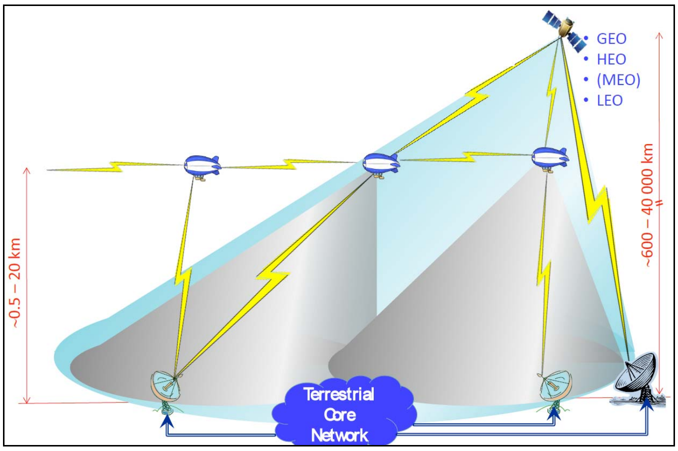


Fig. 3. Heterogeneous satellite HAPs/UASs-terrestrial Systems.

HAP/UAV payloads could comprise radio-relaying equipment for all applicable kinds of communication services in the appropriate satellite frequency bands. However, to simplify the onboard equipment for a majority of the vessels, and because of the detriment of bandwidth, the use of VHF is recommended as a part of the frequency allotment scheme.

Anyhow, as a network topology subset of any satellite solution, hybrid space-borne/terrestrial (HST) configurations should be developed, particularly for minor communities and in coastal areas, as well as on vessels and offshore installations; being a consequential means to any of the above referenced solutions in providing for a more convenient end-to-end connectivity over the corresponding heterogeneous link.

Additionally, carefully devised HST solutions might also be utilized to extend the coverage of the lower Arctic region from

GEO satellites, if larger and more powerful land station antenna constellations are deemed economically viable.

The major advantages of such heterogeneous systems are that they might be made ad hoc–adaptively tailored to their mission–and deployed much faster and with less efforts and costs than a HEO satellite system, offering among others the following benefits: Easy to deploy; incremental deployments; Flexibility and reconfigurability; Low operational costs (compared to satellites); High elevation; Wide area coverage; Broadcast/Multicast; Mobility.

The frequently mentioned challenges are suggested to be: Regulations; Sense and avoid systems; ATM (Air Traffic Management) integration; Safety and security; Airworthiness – the aircraft suitability for safe flights; Type certification; Availability of radio spectrum resources (frequencies and bandwidth); Human factors and autonomy; Public perception.

Reliable communications links are crucial for search and rescues (SAR) activities. In the Arctic, remotely piloted aircraft systems (RPAS) would be of significant benefit for a fast and large-area SAR. Nevertheless, using any kind of aerial vehicle is regulated by the International Civil Aviation Organization (ICAO), the domestic aviation administrations, and also particularly dedicated regulations for UAV applications. Because of the geographical sectorial interests toward the North Pole, domestic regulations merge in these areas, and flying or operating aerial vehicles there might be practically unmanageable. Furthermore, neither the ICAO regions nor the Arctic SAR boundaries fit the regions regulated by the International Maritime Organization (IMO) in the Arctic.

B. VHF Data Exchange System (VDES)

New potential digital VHF satellite services are envisioned. Driven by the modernization of the global maritime distress safety system (GMDSS) and IMO's maritime e-Navigation strategy, request for new spectrum allocations in the VHF band for satellite usage will be discussed at the upcoming world radio conference (WRC) in 2015 under Agenda 1.16 in accordance with Resolution 360 of WRC 12. The initial approaches are looking at a system with possible data rates of about 300 kbit/s, the main goal being to protect the already defined satellite AIS bands. In this way the AIS system can be offloaded from all the additional services exploiting its payload. Furthermore, broadcasting services for the satellite-to-ship links are envisioned and can be particularly important for safety related information.

C. Usage of Existing Scheduled Aircraft

The collection of measurement data, AIS signals, or other M2M telemetry information could also be done by airliners. These scheduled aircraft fully cover the Arctic because of their polar routes with at least 5–10 contacts per day [18]. However, they would have to be fitted with appropriate radio receiver(s) and signal storage devices. After landing or after reentering satellite or terrestrial communications infrastructure, the data could be fed into the pertinent data base.

VII. SUMMARY

Better accessibility to the Arctic because of its reduced floating ice coverage during the last decades, has increased communication demands from all stakeholders in this area (fishery, exploration, leisure, expedition, cargo shipping, air traffic, etc.). In this article, the state-of-the art communication in the Polar Regions is surveyed.

The immediate needs for new systems because of lack of communications infrastructure, correction signals for GNSS augmentation systems, harsh weather conditions, and vessel motions are emphasized.

For reaching the goal of adequate broadband coverage before new satellite systems might, if ever, be realized for that purpose, novel innovative solutions and further associated research should be focused by investigating hybrid architectures. Using hybrid space-borne/terrestrial (HST) configurations could allow a much faster and less costly deployment than a HEO satellite system to meet the Arctic users' requirements. Furthermore, such HST architecture could be adaptively tailored to its mission and could be made ad hoc. Additionally, scheduled aircraft could support communication in the Arctic and new digital VHF services could enable further communications capabilities.

The Arctic is still a niche market for communication compared to other regions in the world. Nevertheless, access to large resources of energy (oil and gas), fish, and raw materials is expected, and this requires communications to support demanding maritime operations, surveillance, and emergency response tasks satisfactorily. In the end, we are always bound to safeguard the impact on this fragile ecosystem by the steadily increasing activities in the area.

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TABLE II. DEMANDS ON DATA THROUGHPUT FOR DIFFERENT APPLICATIONS IN THE MARITIME [8] AND AERONAUTICAL DOMAIN.

Applications		Demand on data throughput
Maritime	**Emergency messaging** (SAR, distress, positioning…)	Low (<10 kbit/s)
	Mandatory reporting (factual reports, arrival info…)	Low (<10 kbit/s)
	Operation and navigation reporting (ship-land status reporting…)	Low (<10 kbit/s)
	Technical maintenance (telemetry, sensor reporting)	Low (<50 kbit/s)
	Training and qualification (data exchange for training purposes, ship-to-shore, often real time)	Medium (<1 Mbit/s)
	Safety and technical monitoring (safety critical data)	Medium (<1 Mbit/s)
	Infotainment (crew and passenger; (HD)TV, Internet)	High (<10 Mbit/s)
	Special purpose applications (oil exploration, unmanned demanding, video conferencing, offshore operations…)	High (<20 Mbit/s)
Aeronautical	**Air traffic control** (minimal demand) (scheduled and nonscheduled flights, helicopter…)	Low (<10 kbit/s)

TABLE III. ARCTIC COMMUNICATIONS COVERAGE LIMITATIONS.

	System	Characteristics	Polar (>80°N)	Sub-Polar (70°N-80°N)
Terrestrial systems	HF, MF	Safety related messages and voice only	Unsuitable for digital communications	Unsuitable for digital communications
	VHF, digital VHF	Line-of-sight voice and very narrowband data	No base stations	Few base stations
	GSM, 3G	Line-of-sight voice and very narrowband data	No base stations	Very few base stations
	LTE/4G, WiMAX	Line-of-sight voice and very broadband data	No base stations	Insignificant deployment
Satellite Systems	GEO (Inmarsat, VSAT)	Medium capacity – low to moderate latency	Unavailable	Limited availability and quality
	LEO (Iridium)	Medium capacity – high and variable latency	Potential problems with capability / quality	Potential problems with capability / quality
	HEO	Properties comparable with GEO	Currently unavailable	

TABLE IV. EXISTING AND PLANNED ARCTIC COMMUNICATIONS SATELLITE SYSTEMS.

	Inmarsat	Iridium	Cospas-Sarsat	Globalstar	Gonets
Orbit	GEO	LEO	LEO	LEO	LEO
Arctic coverage	Max. up to 81°N	Total	Total	Max. up to 80°N	Total
Status	Existing	Existing	Existing	Existing	Existing
Capabilities	450 kbit/s	9.6 kbit/s (max. 130 kbit/s)	Distress messaging	9.6 kbit/s	64 kbit/s
	Iridium NEXT	Arktika	PCW	ARGOS-4	ASK
Orbit	LEO	HEO	HEO	LEO	HEO
Arctic coverage	Total	Russian sector	North American sector	Total	European sector
Status	Operational in 2017	Planned launch in 2015 (delayed)	Planned launch in 2016 (delayed)	Planned launch in 2016	Envisioned launch in 2020
Capabilities	1.5 Mbps air traffic	Observation, meteorology, communications	Meteorology, communications	Observation, communications	Communications